CLAYS OF ST. JOHN'S VICINITY,

ARIZONA AND NEW MEXICO

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CLAYS OF ST. JOHN'S VICINITY, ARIZONA AND NEW MEXICO

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THESIS

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CLAYS OF ST. JOHN'S VICINITY,

ARIZONA AND NEW MEXICO

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A B S T R A C T

Clay minerals from the Triassic, Cretaceous, and Quaternary Systems, studied by X-ray, microscopic, and differential-thermal methods, include kaolinite, montmorillonite, illite, chlorite, and interlayered mixtures of these.

There was continuous deposition of kaolinite throughout Triassic time and during part of the Cretaceous. Kaolinite reappeared in the Quaternary Richville Formation.

Montmorillonite, indicative of previous volcanic activity, is the main clay-mineral constituent of the Triassic Chinle Formation.

The transgressive-regressive character of the Cretaceous sediments is reflected by their clay-mineral content.

The sources of the Richville Formation were the rocks that still crop out in the area.

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INTRODUCTION

Visitors to the Painted Desert National Monument along the transcontinental highway (U. S. 66) about 45 miles northwest of St. John's are amazed by the bright display of colors. The same kind of rocks crop out prominently in the Petrified Forest 35 miles northwest of St. John's and also in the St. John's vicinity (Figs. 3, 4, 5, 6 and 7). It would be difficult for any normally curious person to live among these outcrops without wondering about the origin of the colors. My curiosity prompted me to begin this investigation of the clay minerals.

It turned out that the impulse did not correspond with the result. There is no relationship between the clay minerals and the color, but the clay materials of the Triassic Chinle Formation do play an important role in the development of the brightly colored badlands, and the Cretaceous rocks of the canyons have clay materials as a major constituent. Clay also occurs in the thick Pleistocene Richville Formation. Most significantly, the composition of the clays is an important clue to the geological history of the deposits.

LOCATION

The "St. John's vicinity" of this report is an area of approximately 1,000 square miles. Its southwest corner is at Springerville, Arizona. It is bounded on the west by U. S. Highway 260 in Apache

County, Arizona. The northwest corner is the intersection of Highway 260 with Carrizo Wash. The northern boundary extends thence up Carrizo Wash to the mouth of Wahee Wash; thence up Wahee Wash to the Arizona-New Mexico state line; thence due east into New Mexico. The eastern boundary is approximately 108° 50' W. in Valencia and Catron counties, New Mexico. The southern boundary, U. S. Highway 60, extends from a point in Catron County to Springerville, Arizona.

PREVIOUS WORK

The only published work on the clays of this area was done by Allen (1930), who made microscopic examinations of material collected by Camp from the Chinle Formation. Allen concluded that the lower, gray shale is predominantly composed of bentonite, which he identified by means of relic-glass structure, euhedral minerals, sanidine that originates only in volcanic rocks, characteristic mineral and chemical composition, waxy luster, and swelling in water. Among the minerals detected were soda sanidine, quartz, biotite, magnetite, apatite, and zircon. He further stated that the colors of the purple and red layers of Chinle shales are due to specks of iron oxide that developed after deposition in response to the environment under which the sediments accumulated.

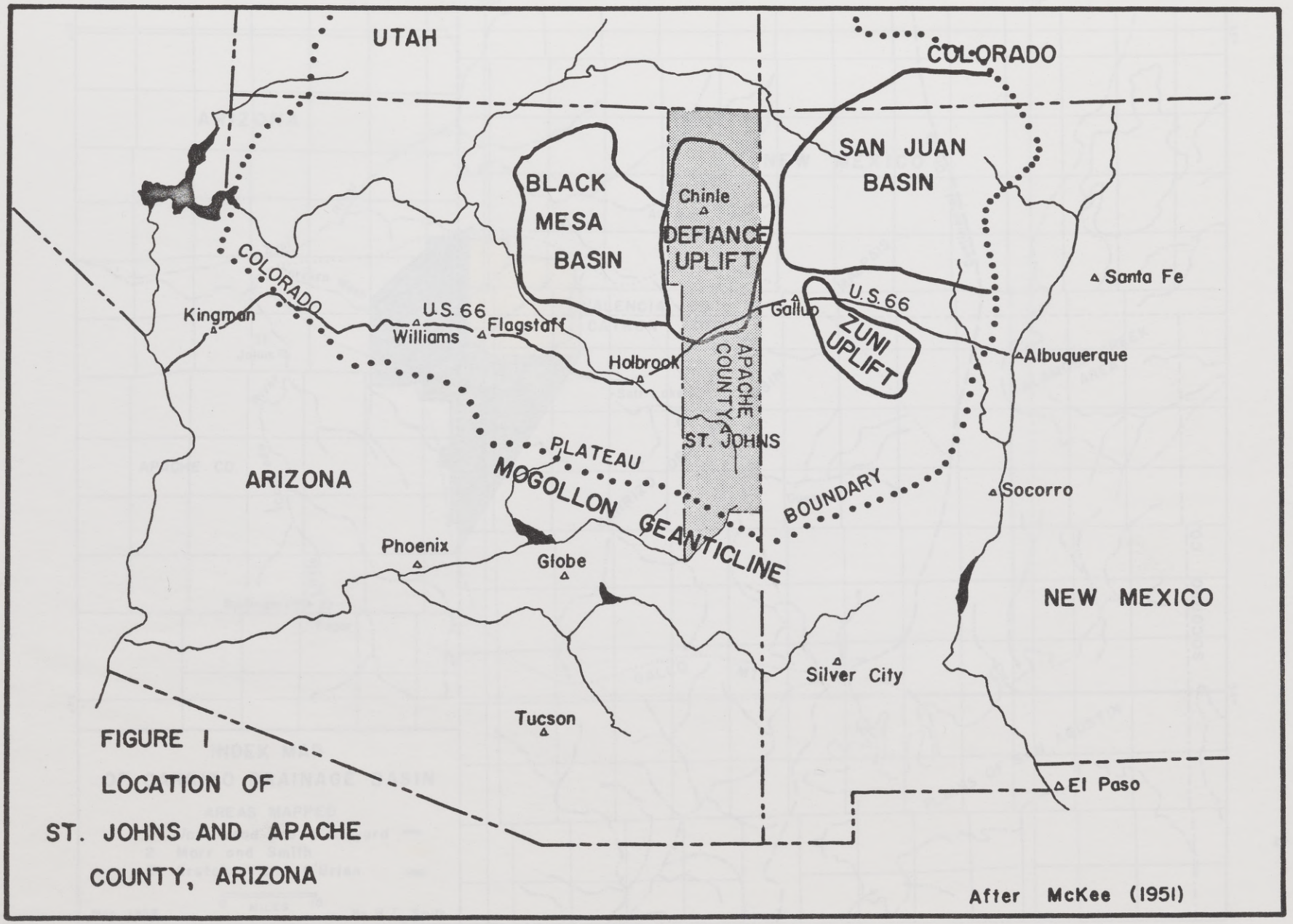


FIGURE 1
LOCATION OF
ST. JOHNS AND APACHE
COUNTY, ARIZONA

Figure 2

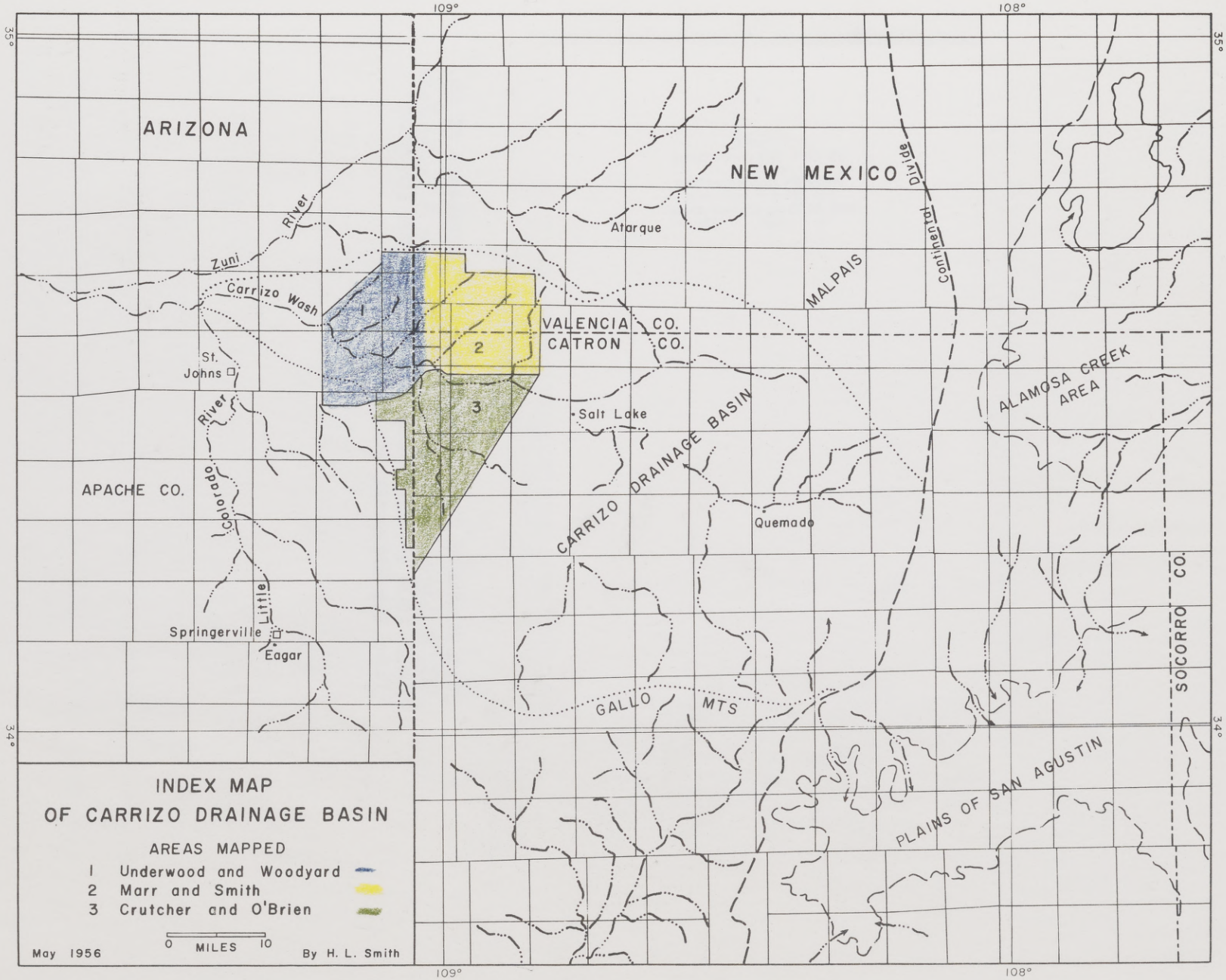

109°
108°
35°
34°
ARIZONA
NEW MEXICO
Continental Divide
Atarque
Zuni River
Carrizo Wash
MALPAIS
VALENCIA CO.
CATRON CO.
St. Johns
Salt Lake
ALAMOSA CREEK AREA
CARRIZO DRAINAGE BASIN
Colorado River
APACHE CO.
Quemado
SOCORRO CO.
Little
Springerville
Eagar
GALLO MTS
PLAINS OF SAN AGUSTIN
1
2
3
INDEX MAP
OF CARRIZO DRAINAGE BASIN
AREAS MAPPED
1 Underwood and Woodyard
2 Marr and Smith
3 Crutcher and O'Brien
0 MILES 10
May 1956
By H. L. Smith

Figure 3

View westward from a point one mile northeast of St. John's (Sec. 19, T. 13 N., R. 29 E., G. & S. R. M.). Shown here is the Chinle Formation about 200 feet above the Shinarump conglomerate.

Figure 4

View northeastward from basalt about 15 miles east of St. John's (Sec. 2, T. 12 N., R. 30 E.). Messrs. Robertson, Underwood and Green are sitting on the rim of the basalt. The tree covered slope in the foreground is landslide material from the basalt, while the distant barren valley is cut into the Chinle Formation.

FIELD PROCEDURE

Under the field supervision of Ronald K. DeFord eight Master's-degree candidates from The University of Texas mapped part of the area during the summer of 1955, and a Ph. D. candidate mapped the remainder during the summers of 1954 and 1955. The clay-mineral content of the rocks mapped by the nine students is the subject of this thesis. Boundaries of the individual areas mapped by each part are as shown in Table 1.

Geologic contacts, culture, U. S. Coast and Geodetic survey triangulation stations, and other features were plotted on air photographs with a soft-lead pencil. These lines were checked by a stereoscope and then traced in ink so that they would not be effaced unintentionally during later field work.

Plate I, a geologic map of the Garcia Ranch, is the result of two months' field investigation by James R. Underwood and myself. A composite map of St. John's vicinity is being prepared by Sirrine (1956).

ACKNOWLEDGMENTS

I am indebted to Professor Ronald K. DeFord for invaluable aid in the field, and for suggestions and criticisms in the preparation of this thesis. I am also indebted to Professor E. C. Jonas for his great aid in interpreting the X-ray data, and criticisms of this manuscript.

Table 1

BOUNDARIES OF THE INDIVIDUAL AREAS MAPPED

BY PARTIES CONTRIBUTING CLAY SAMPLES

Party	Approximate Boundaries			
	N	S	E	W
T. E. Green, Jr. R. S. Robertson	Carrizo Wash	Salt Lake Rd.	R. 30 E.	U. S. Hwy. 666
J. R. Underwood, Jr. K. E. Woodyard	Wahee Wash	Salt Lake Rd.	109° 00' W.	R. 29 E.
R. J. Marr H. L. Smith	34° 40' N.	Salt Lake Rd.	108° 50' W.	State line
T. D. Crutcher B. R. O'Brien	Salt Lake Rd.	34° 15'	Sec. 9, T.3N., R.19W. to Sec. 8, T.1S., R.21W. N. M. P. M.	1 mile east of state line
G. K. Sirrine	Salt Lake Rd.	U. S. Hwy. 60	State line	R. 27 E.

See Figure 2

Professor Robert L. Stone was also helpful with his criticism of the text.

Appreciation is expressed to Mr. James R. Underwood, Jr. for his assistance, co-operation and companionship during the field investigation.

To all members of the mapping parties--Messrs. Green, Robertson, Marr, Smith, Crutcher, O'Brien, Rehkemper, Rutledge and Sirrine--I am grateful for aid and advice in mapping and preparation of the report and for contributing samples.

I wish to thank Professor Robert L. Folk for the active interest he took in the project.

The field work could not have been undertaken without the permission of the Garcias, Lynchs, Barths, and Hinksons, who own the ranches in the area. Especially kind were the Garcias, who allowed me and my field partner to live in a cabin on their ranch. Their hospitality was the more appreciated during the time when a great search for valuable minerals by many people, both honest and otherwise, brought suspicion on all geologists.

CLAY TECHNIQUES

LABORATORY PROCEDURE

Two methods of sample preparation were used in preparing specimens for X-ray diffraction. Oriented and powdered samples were used. Care was taken during field collection to assure the use of only unweathered specimens.

The specimen was first examined under a binocular microscope to determine lithology. The color was then determined by use of the Rock-Color Chart (Goddard et al., 1951).

Oriented samples were prepared in the following manner. The specimen was ground to a fine powder with a porcelain mortar and pestle, and then poured into a large (500 ml or 250 ml) glass beaker. The beaker was then filled with distilled water and the mixture thoroughly agitated with a glass stirring rod to assure equal distribution of all the particles. A 2-micron fraction, obtained by allowing the liquid to settle for two hours and then pipetting off the top, was poured into a 50 ml glass beaker, which was placed in an oven which was held at a temperature of about 80° C. After most of the water had been evaporated and the remaining portion had reached a thick consistency, it was poured onto glass microscope slides and allowed to evaporate at room temperature. Individual flake-shaped clay particles settling out of this mixture produced an oriented collection of clay material on the slide.

Powder samples were prepared by grinding the specimen to as fine a powder as possible with an agate mortar and pestle. The powder was placed on a glass plate and packed firmly into an aluminum frame. The sample was then ready for X-ray diffraction.

A Type 1 - Model BR - General Electric Spectrogoniometer was used for all X-ray work. The detection and recording unit was a Berkley Model No. 2 SPG Detector.

The Type 1 SPG Spectrogoniometer is a precise mechanical instrument for the direct measurement of the angular positions of all practical X-ray diffraction effects. The instrument functions according to Bentano parafocusing geometry for recording diffraction data in the maximum Bragg angle range from minus 10° to 180° two-theta. The apparatus provides for precise measurement of the Bragg angle at an accuracy of 0.001° throughout the range. The resolution of the diffraction effects varies with accessories and techniques in the range from 0.002° to 0.2°.

Copper radiation was used throughout with a supply of 23 milliamperes and 35 kilovolts. The accessories used varied with the degree of resolution needed, but for 95 per cent of the samples a 3° beam slit, medium resolution soller slit, 0.2° detector slit and 4-layer nickel filter were used. When better resolution was needed, a 1° beam slit and 1-layer nickel filter were employed.

DEFINITIONS

Almost all the following discussion has been paraphrased from Grim (1953).

The term clay implies a natural, earthy, fine-grained material that develops plasticity when mixed with water. Chemical analyses of clays show them to consist essentially of silica, alumina, and water, although iron, alkalies, and alkaline earths are present in many of them.

No genetic significance is attached to the term clay. It may be used for material that is the product of weathering, or material that has been formed by hydrothermal action, or material that has been deposited as a sediment.

As a term denoting particle size clay implies the smallest size of grains. The widely used Wentworth scale defines clay as that fraction of material with grain diameter less than four microns. Soil investigators put the upper size limit at two microns. The natural tendency is for the grain diameter of clay minerals to be concentrated in a size class of less than about two microns or for naturally occurring larger clay-mineral particles to break down easily to this size when slaked in water. As the grain diameters of few nonclay minerals are smaller than about one to two microns, a natural separation at about two microns is possible. It is for this reason that the less-than-two-micron fraction was used in preparing samples for this investigation.

About 1924 Ross and others of the U. S. Geologic Survey showed that the components of clay materials are crystalline and few. They were called clay minerals.

The clay minerals are hydrous aluminum silicates, in some of which magnesium or iron may substitute wholly or in part for the aluminum. Alkalies or alkaline earths may be present as essential constituents in some of them. Some clays are composed of a single clay mineral, but many are mixtures.

Two structural units are involved in the atomic lattices of most of the clay minerals. One unit consists of two layers of closely packed oxygens or hydroxyls in which aluminum, iron, or magnesium atoms are embedded in octahedral coordination, so that they are equidistant from six oxygens or hydroxyls. The second unit is built of silica tetrahedrons. In each tetrahedron a silicon atom is equidistant from four oxygens, or hydroxyls if needed to balance the structure.

Clay minerals of four groups were found in the rocks cropping out in the vicinity of St. John's. Their generalized formulas are given below:

Kaolinite — $Al_2Si_2O_5(OH)_4$

Montmorillonite — $(AlMg)_2Si_4O_{10}(OH)_2Na.$[33]

Illite — $(OH)_4K_2(Si_6.Al_2)Al_4O_{20}$

Chlorite — $(OH)_4(SiAl)_8(Mg.Fe)_6O_{20} + (Mg.Al)_6(OH)_{12}$

The nomenclature of kaolin minerals as presented by Ross and Kerr (1931) has been generally accepted. According to them,

> . . . by kaolin is understood the rock mass which is composed essentially of a clay material that is low in iron and usually white or nearly white in color. The kaolin-forming clays are hydrous aluminum silicates of approximately the composition $2H_2O.Al_2O_3.2SiO_2$ and it is believed that other bases if present represent impurities or adsorbed materials. Kaolinite is the mineral that characterizes most kaolins.

The structural basis of kaolinite is a single tetrahedral sheet of silica and a single octahedral sheet of alumina combined in a unit so that the tips of the silica tetrahedra and one of the layers of the octahedral sheet form a common layer. The minerals of the kaolinite group consist of sheet units of the type just described continuous in the a and b directions and stacked one above the other in the c direction.

The name montmorillonite is used currently both as a specific mineral name and as a group name for all clay minerals with an expanding lattice, except vermiculite. The currently accepted structure for montmorillonite is that it is composed of units made up of two silica tetrahedral sheets with a central alumina octahedral sheet. All the tips of the tetrahedra point in the same direction and toward the center of the unit. The layers are continuous in the a and b directions and are stacked one above the other in the c direction. In the stacking

of the silica-alumina-silica units, oxygen layers of each unit are adjacent to oxygen layers of the neighboring units with the consequence that there is only a weak bond through the interlayer ions and excellent cleavage between them. The outstanding feature of the montmorillonite structure is that water and other polar molecules, such as certain organic molecules, can enter between the unit layers, causing the lattice to expand in the c direction. The c-axis dimension of montmorillonite is, therefore, not fixed but varies from about 9.6a.u., when no polar molecules are present, substantially to complete separation of the individual layers.

The term illite is used for the mica-like clay minerals with a 10a.u. c-axis spacing which shows substantially no expanding-lattice characteristics, of both dioctahedral and trioctahedral types and of muscovite and biotite crystallizations. The basic structural unit is a layer composed of two silica tetrahedral sheets with a central octahedral sheet. The unit is the same as that for montmorillonite except that some of the silicons are always replaced by aluminums and the resultant charge deficiency is balanced by potassium ions. The unit layers extend indefinitely in the a and b directions and are stacked in the c direction.

The term chlorite has been used for a group of green hydrous silicates in which ferrous iron is prominent and which are closely related to the micas. Structurally the chlorites are regular interstratifications of single trioctahedral mica layers and brucite layers.

Only recently have chlorites been recognized as important clay minerals, and it is likely that they are more abundant than has been previously realized. They are difficult to detect when small amounts are mixed with other clay materials. The identification of chlorite is particularly difficult when kaolinite is one of the constituents of the clay material.

INTERPRETATION OF DATA

The values of 2-theta were read directly from the spectrometer trace, and were accurate to 0.1°. These values were translated to d-spacings by consulting the tables of Switzer, Axelrod, Lindberg, and Larsen (1948).

The determination of the kaolinite group was simple, the prominent basal reflections at about 7.14 a.u. (001) and 3.57 a.u. (002) being adequate for identification.

Montmorillonite possesses the property of adsorbing certain organic molecules between the individual silicate layers with a consequent shift in the c dimension. Ethylene glycol was added to samples suspected of being montmorillonitic, and montmorillonite was identified by the shift of either a 12.5 a.u. or 15 a.u. reflection to 17 a.u.

The illite minerals were identified by their (00ℓ) spacing with the first order at about 10 a.u.

Notwithstanding that the chlorite clay minerals may be confused

with the kaolinite minerals, the third order at 4.7 a.u. was usually taken to indicate the presence of chlorite. Chlorites rich in iron have weak first and third order reflections, and differentiation from kaolinite is difficult.

In a mixture that consists of a random interstratification of two clay minerals, wherein only a few layers of one type are present, the reflections will differ very little from those of the dominant layer. As Grim (1953) remarked:

> If, however, the second type of layer is present in considerable abundance (10%), new diffraction effects will arise; in particular, a nonintegral series of reflections is obtained from the basal planes . . .
>
> . . . In mixed-layer structures the basal reflections are composites of adjacent reflections of the same orders of the different layers and at an intermediate position between them, or a composite of overlapping reflections of different orders of the different layers. The position and intensity of the composite reflections will vary with the relative abundance of the different individual layers . . .

ORIGIN AND OCCURRENCE OF CLAY MINERALS

The clay minerals in a given sedimentary rock may have formed in any one of several ways (Folk, 1954). They may have formed by:

(1) reworking without chemical change through simple disaggregation of older clay-bearing rocks;

(2) chemical weathering of minerals containing aluminum and silicon, chiefly feldspar but including mafic minerals and older clay minerals;

(3) subaqueous devitrification of volcanic ash;

(4) diagenetic changes taking place in a marine environment after deposition;

(5) diagenetic changes taking place during deep burial, by migration of connate solutions, or by incipient metamorphism;

(6) intense metamorphism;

(7) post-diagenetic weathering, taking place after the outcrop is once more exposed to the surface and weathered.

Almost all the following discussion has been paraphrased from Folk (1954).

Disaggregation of older clay-bearing rocks yields chiefly illite, because most shales are marine and composed of illitic clay which can be reworked without change. Small amounts of chlorite and kaolinite come from this source. Slates and phyllites yeild illite or chlorite, but little kaolinite and almost no montmorillonite, as these are upgraded

in metamorphism.

The effect of weathering on clay minerals may be understood if one keeps in mind that clays, because of their large surface area, are highly active chemically, and will react to attain equilibrium with the ions in their environment. The ions present will depend on the source rock and the climate (degree of leaching). Under incomplete leaching (arid climate), potassium and magnesium remain in the soil and if basic rocks are being weathered, montmorillonite and sometimes chlorite form. If the rocks are acidic, illite and sometimes montmorillonite form. With complete leaching (warm, humid climate), both potassium and magnesium are removed and kaolinite forms ultimately regardless of the source rock. It has also been found that the calcium ion, like magnesium, retards the formation of kaolinite and aids the formation of montmorillonite, so that few limestones contain kaolinite.

Devitrification of volcanic ash yields montmorillonite and rarely illite; if the product remains in situ, it is called bentonite. The main source of montmorillonite is thought to be volcanism.

Sea water contains abundant potassium, sodium, and magnesium ions, and the clay minerals, when brought into this environment, react accordingly. Kaolinite is least stable and rapidly converts to chlorite or illite. Montmorillonite may form to begin with in sea water, but may then slowly convert to chlorite or illite depending on whether it picks up magnesium or potassium ions. Kaolinite is stable in fresh water and

persists, if calcium is not too abundant. In fresh water montmorillonite persists, especially if calcium is present.

Kaolinite and montmorillonite appear to be gradually destroyed on deep burial. If the environment is rich in magnesium or iron, chlorite forms; if potassium is present, illite develops.

RESULTS

Altogether 99 samples were examined with the spectrogoniometer. These samples represent every formation in the St. John's vicinity with the exception of the Shinarump conglomerate. By adding the maximum measured thickness of each formation, one obtains a cumulative maximum of about 3370 feet. A breakdown of the measured thicknesses and number of samples from each formation is as follows:

Formation	No. of Samples	Thickness in Feet
Richville	12	130
Eagar	5	940?
Mesaverde	3	600
Mancos	6	390
Dakota	11	110
Chinle	59	1100?
Shinarump	0	50
Moenkopi	3	50
Total	99	3370

The samples were collected throughout an area of about 1000 square miles by five field parties (Table 1). Sampling of the Moenkopi, Chinle, Dakota, Eagar and Richville Formations is adequate for interpretative work. Samples of argillaceous materials from the Mancos and

Mesaverde Formations were scarce, and any conclusions drawn from their examination may be subject to criticism.

The only other formation for which the possibility exists that a true picture was not obtained is the Chinle. The horisontal distance between the base of the Chinle and the uppermost bed in the area is about 25 miles, and the measured section is a composite of several sections measured along this 25-mile distance. Some lateral variation may occur over a distance that great. However, two sections of the lower 200 feet of the Chinle which were measured about six miles apart showed no appreciable differences in clay-mineral content; lateral variation between these two, if present at all, is slight.

Table 2

RESULTS OF X-RAY TESTS

EXPLANATION OF TABLE

A. Key Number:

Underwood (1956)	U
Sirrine (1956)	S
O'Brien (1956)	O
Marr (1956)	M
Robertson (1956)	R

The second figure tells from which measured section the sample came.

Example: Key No. U-B . . . . Underwood's measured section B.

B. System:

Quaternary	Q
Tertiary-Cretaceous	TK
Cretaceous	K
Triassic	Tr

C. Formation:

Richville	R
Eagar	E
Mesaverde	Mv
Mancos	Ma
Dakota	D
Chinle	C
Moenkopi	Mo

As nearly as possible the order in the table is stratigraphic from youngest sample to oldest.

TABLE I

KEY NO.	UNIT NO. OR SAMPLE NO.	SYSTEM	FORMATION	KAOLINITE	MONTMORILLONITE	ILLITE	CHLORITE	ILLITE-MONTMORILLONITE	CHLORITE-MONTMORILLONITE	ILLITE-CHLORITE MONTMORILLONITE	QUARTZ	$MnCO_3$	$CaCO_3$
U-C	C-48	Q	R	X							X	X	X
U-C	C-39	Q	R	X								X	
U-C	C-34	Q	R	X				X					
U-C	C-30	Q	R	X								X	
S-8	10b	Q	R	X									
S-5	7b	Q	R				X						
U-F	F-15	Q	R				X					X	
U-C	C-19	Q	R	X							X		
U-F	F-9	Q	R									X	X
U-C	C-10	Q	R	X								X	X
U-F	F-1	Q	R	X		X							
U-C	C-2	Q	R					X					
S-6	10b	TK	E					X					
S-6	9b	TK	E					X					
S-6	8	TK	E					X					
S-6	0	TK	E					X					
O-9	17	TK	E					X			X		
O-9	16	K	Mv				X				X		
O-9	14	K	Mv			X					X		
O-9	11	K	Mv			X					X		
M-3	11	K	Ma						X		X		X
M-5	10	K	Ma						X		X		

TABLE I

KEY NO.	UNIT NO. OR SAMPLE NO.	SYSTEM	FORMATION	KAOLINITE	MONTMORILLONITE	ILLITE	CHLORITE	ILLITE-MONTMORILLONITE	CHLORITE-MONTMORILLONITE	ILLITE-CHLORITE MONTMORILLONITE	QUARTZ	$MnCO_3$	$CaCO_3$
M-5	9	K	Ma		X								
M-3	8	K	Ma	X									
M-6	8	K	Ma							X			
M-6	6	K	Ma							X	X		
U-B	B-75	K	D	X				X			X	X	
U-B	B-74	K	D	X						X	X	X	
U-B	B-72	K	D	X								X	
U-B	B-68	K	D	X								X	
U-B	B-66	K	D	X	X						X	X	
U-B	B-61	K	D	X								X	
U-B	B-50	K	D	X		X					X	X	
U-B	B-37	K	D	X							X	X	
U-B	B-31	K	D	X		X					X	X	
U-B	B-25	K	D	X							X	X	
M-3	2	K	D	X									
U-B	B-18	Tr	C							X	X		
U-B	B-16	Tr	C							X	X		
U-B	B-9	Tr	C	X				X			X	X	
U-B	B-1	Tr	C	X				X			X	X	X
U-E	E-58	Tr	C	X								X	
U-E	E-54	Tr	C	X							X	X	
U-E	E-42	Tr	C	X				X			X	X	

TABLE I

KEY NO.	UNIT NO. OR SAMPLE NO.	SYSTEM	FORMATION	KAOLINITE	MONTMORILLONITE	ILLITE	CHLORITE	ILLITE-MONTMORILLONITE	CHLORITE-MONTMORILLONITE	ILLITE-CHLORITE MONTMORILLONITE	QUARTZ	$MnCO_3$	$CaCO_3$
U-D	D-55	Tr	C		X						X	X	
U-E	E-38	Tr	C		X						X	X	X
U-D	D-51	Tr	C		X							X	
U-D	D-46	Tr	C				X				X	X	
U-D	D-37	Tr	C									X	X
U-E	E-32	Tr	C				X						
U-E	E-24	Tr	C	X	X						X	X	
U-D	D-31	Tr	C								X	X	X
U-E	E-16	Tr	C									X	X
U-E	E-4	Tr	C				X					X	
U-D	D-24	Tr	C		X						X	X	
U-D	D-15	Tr	C	X							X	X	
U-D	D-5	Tr	C	X							X	X	
R-1	26	Tr	C				X				X		
U-G	G-22	Tr	C						X		X		
U-G	G-19	Tr	C						X		X		
U-A	A-29	Tr	C	X	X						X	X	
U-G	G-15	Tr	C						X		X	X	
U-A	A-23	Tr	C	X	X						X	X	
U-G	G-12	Tr	C						X		X		
U-A	A-19	Tr	C	X	X						X	X	
U-G	G-5	Tr	C						X		X		

TABLE I

KEY NO.	UNIT NO. OR SAMPLE NO.	SYSTEM	FORMATION	KAOLINITE	MONTMORILLONITE	ILLITE	CHLORITE	ILLITE-MONTMORILLONITE	CHLORITE-MONTMORILLONITE	ILLITE-CHLORITE MONTMORILLONITE	QUARTZ	$MnCO_3$	$CaCO_3$
U-A	A-15	Tr	C		X		X				X	X	
U-G	G-2	Tr	C							X	X		
U-A	A-8	Tr	C		X					X	X		
U-G	G-1	Tr	C		X						X	X	
R-1	21	Tr	C	X	X						X	X	
U-A	A-3	Tr	C	X	X						X		
U-A	A-1	Tr	C	X	X						X		
R-1	18	Tr	C		X						X	X	
R-1	17	Tr	C		X						X		
R-1	16	Tr	C		X						X		
R-1	14	Tr	C		X						X		
R-1	12	Tr	C	X			X				X	X	
R-1	11	Tr	C	X			X				X	X	
R-1	10	Tr	C	X	X						X		
R-1	9	Tr	C	X			X				X		
S-11	16	Tr	C							X	X	X	
S-11	15	Tr	C							X	X	X	
S-11	14	Tr	C			X	X				X		
S-11	12b	Tr	C	X							X	X	
S-11	11	Tr	C	X	X						X	X	
S-11	8	Tr	C	X							X	X	
S-11	7	Tr	C	X							X	X	

TABLE I

KEY NO.	UNIT NO. OR SAMPLE NO.	SYSTEM	FORMATION	KAOLINITE	MONTMORILLONITE	ILLITE	CHLORITE	ILLITE-MONTMORILLONITE	CHLORITE-MONTMORILLONITE	ILLITE-CHLORITE-MONTMORILLONITE	QUARTZ	$MnCO_3$	$CaCO_3$
R-1	8	Tr	C	X	X						X		
R-1	6	Tr	C	X	X						X	X	
R-1	5	Tr	C	X	X						X		
S-11	4	Tr	C	X							X	X	
S-11	3	Tr	C	X							X	X	
S-11	2	Tr	C	X							X	X	
S-11	1	Tr	C	X			X				X	X	
R-1	3	Tr	C	X									
S-9	6	Tr	Mo	X			X						
S-9	4a	Tr	Mo	X							X		
S-9	3	Tr	Mo	X							X		

DISCUSSION AND CONCLUSIONS

Plate II shows in chart form the distribution of clay minerals throughout the stratigraphic sequence investigated.

TRIASSIC SYSTEM

Moenkopi Formation.- The Moenkopi Formation, as well as the other Triassic formations in the St. John's vicinity, was deposited under continental conditions (McKee, 1951). The environment was that of a large river and flood plain similar to the present-day Amazon.

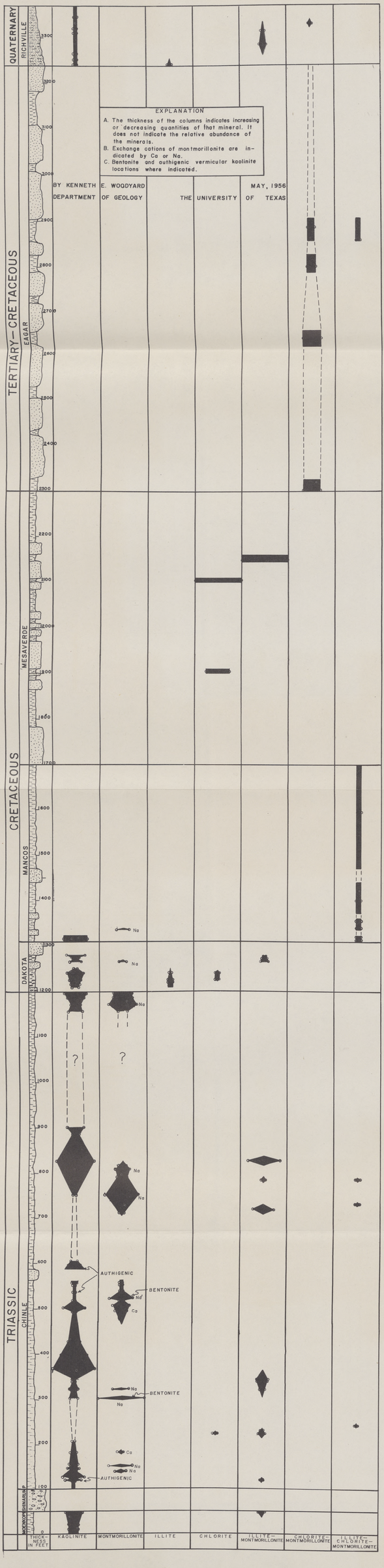
Kaolinite was found throughout the Moenkopi Formation. As kaolinite is formed when weathering is vigorous, its presence is consistent with the conclusion of Dorsey (1926) that during Triassic time the Southwest had a climate similar to that of today's tropical areas.

The uppermost sample of the Moenkopi contained montmorillonite as well as kaolinite. This necessitates a double source, as these two minerals do not form simultaneously in the same area. The montmorillonite is probably reworked bentonite and is indicative of the beginning of the orogeny and volcanism which was responsible for the deposition of the Shinarump conglomerate.

Shinarump Formation.- The silica-cemented Shinarump conglomerate was not tested for clay mineral content for two reasons. First, disaggregation of the rock would have been difficult, and second, chemicals used in the disaggregation would cause exchange reactions and change the

PLATE II

STRATIGRAPHIC POSITION OF CLAY MINERALS, ST. JOHN'S VICINITY



examined a thin section of the authigenic kaolinite and concluded that it grew by physically pushing aside the other grains in the rock.

Montmorillonite is sporadic throughout the section; where present, it forms the greatest part of the clay minerals. Either sodium or calcium is the exchange cation. Field relationships suggest that the Ca montmorillonite developed from the Na montmorillonite owing to a local enrichment by calcium. Such popcorn-size nodules of calcite as are locally present in the claystone could have furnished the calcium necessary for exchange reactions. Extensive Quaternary travertine is suspected of influencing further exchange reactions between the calcium and sodium montmorillonites, but there are insufficient data for definite conclusions.

Allen (1930) stated that the lower gray-shale beds are predominantly composed of montmorillonite and have pebbles which show a structure similar to pumice. His largest pebble was 0.6 by 0.9 mm, but the majority were much smaller. He found a white clayey sandstone, which, according to him, could be produced only by mixing products of erosion with those of volcanism. Bentonitic clay formed the matrix. In other samples he found flattened bentonitic clay pellets up to 2 cm long.

The part of the Chinle observed by me shows marked similarity to that described by Allen. Nevertheless I observed bentonite, as herein defined, in only two places. In thin section the Chinle claystone shows montmorillonite pebbles with a kaolinite matrix.

Figure 5

Westward view of a section cut into a travertine hill along Carrizo Wash in the western part of the Garcia Ranch, (Sec. 17, T. 13 N., R. 30 E.). Underwood is inspecting the Platt Member of the Chinle Formation, which is a cobble conglomerate at this place. The hill is capped by a 6-foot travertine deposit.

Some of the Chinle montmorillonite behaved peculiarly in that it expanded to only 16 a.u. when treated with ethylene glycol. This problem received only minor consideration, and no explanation is offered. It is the opinion of E. C. Jonas that such large ions as uranium or organic ions are blocking the expansion.

The third major clay-mineral component is an interlayered mixture of illite and montmorillonite. Chlorite and an interlayered mixture of chlorite, illite and montmorillonite were also detected.

A multiple source is necessary to obtain this suite of clay minerals. Allen and Balk (1954) concluded that the heavy minerals and abundant montmorillonite indicate a mixture of volcanic and nonvolcanic material. Differential-thermal analyses suggested to them that the Chinle is a product of uninterrupted sedimentation.

The presence of kaolinite throughout the section strongly suggests that the warm, humid climate during Moenkopi deposition continued throughout the deposition of the Chinle formation. The likely sources of the undulose quartz, igneous quartz, plagioclase feldspar, chlorite fragments, muscovite, and biotite observed in thin section were outcrops of both basic-igneous and metamorphic rocks. In addition its pebbles containing crinoid stems indicate outcrops of Paleozoic sedimentary rocks.

The sporadic distribution of the montmorillonite suggests periodic volcanic activity or repeated uncovering and redeposition of

Figure 6

View southward of the Chinle Formation near the Garcia Ranch Headquarters, (Sec. 19, T. 13 N., R. 31 E.). The unconsolidated sand and sandstone boulders on the surface formed by the weathering of the Platt sandstone.

bentonite. The latter seems the more probable. Periodic volcanic activity probably has produced bentonite beds; yet these were observed at only two localities. Furthermore, recent deposits of bentonite do not have the massive thickness characteristic of the beds of claystone in the Chinle.

Inasmuch as an interlayered mixture of illite and montmorillonite could not develop in an environment suitable for the preservation of kaolinite and montmorillonite, it must have been brought in and deposited as such from the source area.

CRETACEOUS SYSTEM

Dakota Formation.- According to McKee (1951),

> Deposits of Upper Cretaceous age were accumulated across northern Arizona in and near a sea that expanded westward from the Rocky Mountain trough.

The Dakota Formation of the St. John's vicinity is composed of a basal conglomerate and alternating lignitic shale and sandstone. Allen and Balk (1954) concluded that the shale and fine sandstone were deposited in lagoons and the sandstone was a bar and beach deposit of the transgressing sea.

Kaolinite, present in all the samples tested, is the dominant clay mineral of the Dakota Formation. As kaolinite rapidly converts to chlorite or illite while in a marine environment, and is stable in fresh

Figure 7

View southward in "Box Canyon" of Wahee Wash, (Sec. 32, T. 15 N., R. 31 E.), one mile southwest of Lynch Ranch Headquarters. Underwood is standing by the basal conglomerate of the Dakota Formation. The black beds immediately above the conglomerate are lignitic shales and are overlain by the first massive sandstone of the Dakota.

water, the presence of kaolinite is evidence of the continental environment for the deposition of the shale facies of the Dakota.

The source for the Dakota sediments was partly Triassic and partly Jurassic rocks, both of which contain kaolinite. The content of the Triassic rocks was discussed above. No Jurassic rocks are present in the St. John's vicinity, and none were examined, but Leopold (1943) has pointed out the presence of kaolinite in the Jurassic rocks of the Colorado Plateau (Fig. 1). Thus a supply of kaolinite was available in the rocks contributing sediments during the deposition of the Dakota.

Chlorite, illite, and an interlayered mixture of illite and montmorillonite compose the remainder of the clay minerals in the Dakota. These minerals are not formed in an environment which is suitable for the preservation of kaolinite, and were, therefore, deposited with the kaolinite. Like the Kaolinite, these minerals were derived from Triassic and Jurassic rocks.

Mancos Formation.- The Mancos Formation is composed of alternating sandstone and shale, and, except for the lowermost shale member, is the marine facies of deposition in the fluctuating Cretaceous sea.

Kaolinite is present only in the lowermost shale unit of the Mancos and indicates the last continental deposition of Mancos sediments in this area.

An interlayered mixture of montmorillonite, chlorite, and illite is present throughout the Mancos, and developed from a crystalline source.

Marr (1956) has reported a bed of bentonite in the Mancos in Valencia County, New Mexico, and Muehlberger (1955), has reported numerous thin beds of bentonite in northern New Mexico. Thus, volcanic ash which converted to bentonite was contributed to the Mancos sediments from a source north of the St. John's vicinity.

Mesaverde Formation.- The Mesaverde Formation is a series of massive sandstone beds and thin shale beds. Allen and Balk (1954) stated that it is the result of repeated transgressions and regressions of a shoreline with abundant sand and silt coming from a crystalline source on the southwest.

The three samples from this formation that were tested by me have a clay-mineral content that support their conclusion. The two lower samples have a large chlorite content, and the upper sample has a montmorillonite-illite-chlorite mixture. A crystalline source for chlorite is possible, if slates or phyllites are disaggregated, if basic rocks are incompletely leached, or if kaolinite or montmorillonite are formed by the weathering of a crystalline rock and deposited in the sea and then converted to chlorite. A sedimentary source is also possible, but the likelihood of a crystalline source being made available by the disturbances responsible for the volcanism during Mancos deposition makes the crystalline source for Mesaverde sediments the more acceptable.

The illite-montmorillonite-chlorite mixture had the same crystalline source, but the montmorillonite has incompletely converted to

chlorite.

TERTIARY-CRETACEOUS

Eagar Formation.- The Eagar Formation, of doubtful age and deposited under continental conditions, is an arkosic sandstone with a small amount of shale (Sirrine, 1956). Its type locality near Eagar, Arizona, is described by Sirrine (1956).

Very little clay material is present in the Eagar. Of the five samples tested, a montmorillonite-chlorite mixture was the only clay mineral found. This mixture suggests an arid climate and incomplete leaching of basic rocks as a source.

QUATERNARY SYSTEM

Richville Formation.- The Richville is a Pleistocene formation of very loosely consolidated sandstone with small stringers of siltstone.

The clay minerals present are kaolinite, illite, illite-montmorillonite mixtures, and chlorite-montmorillonite mixtures. This mineral suite very strongly suggests sedimentary rocks now cropping out in the St. John's vicinity as the source. The kaolinite is from the Triassic and older Cretaceous rocks, illite from the Chinle Formation, the illite-montmorillonite mixture from the Chinle and Mesaverde Formations, and the chlorite-montmorillonite mixture from the Eagar.

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PLATE I

LEGEND

QUATERNARY SYSTEM

- Qal — Alluvium
- Qso — Gravel
- Qto — Gravel
- Qte — Gravel
- Qb — Basalt
- Qr — Richville Formation
- Qt — Travertine
- Qbl — Basalt Landslide
- Qtl — Travertine Landslide

AGE RELATION TO ADJACENT FORMATIONS

CRETACEOUS SYSTEM

- Km — Mesaverde Formation
- Km — Mancos Shale
- Kd — Dakota Sandstone

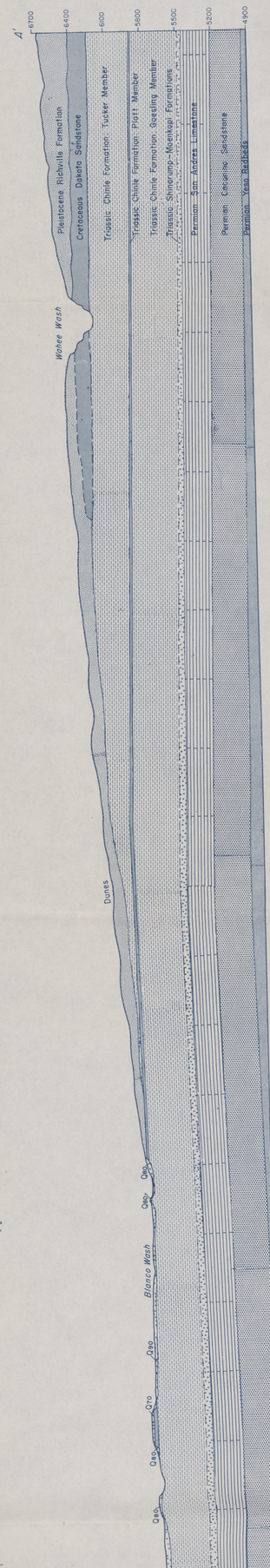
TRIASSIC SYSTEM

Chinle Fm.

- Trct — Tucker Shale Member*
- Trcp — Platt Sandstone Member*
- Trcg — Goesling Shale Member*

* Field names only—not formally proposed

- Mineral Prospect — X
- Water Wells
  - Nonflowing With Windmill Or Pump — ⊙
  - Flowing — ●
  - Spring — ●
- Wire Fence
- County Road
- Ranch Road
- U.S.C.& G.S. Triangulation Station — △HINKSON
- Township Corner Recovered — ◇
- Measured Section — A
- Earthen Tank



GEOLOGY OF GARCIA RANCH
APACHE COUNTY, ARIZONA

MAPPED BY

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SUMMER 1955

SUPERVISED BY R.K. DeFORD
DEPARTMENT OF GEOLOGY
THE UNIVERSITY OF TEXAS

MAP PRINTED MAY, 1956

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MEAN DECLINATION 1955

Vertical exaggeration 4.17 to 1